Reflection imaging the 35°-dipping normal fault that bounds the Basin & Range Province

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Summary

The Surprise Valley Fault (SVF) separates the Warner Range and the Surprise Valley basin at the intersection of the NV-CA-OR borders and forms the western margin of the Basin and Range extensional province at this latitude.

The SVF is a single, east-dipping, large-offset normal fault that developed within essentially unfaulted volcanic plateau sequences to the south, east and west (*Figure 1*). Much of the slip on the SVF may post-date the youngest lavas mapped east and west of the SVF dated at 8-4 Ma (Carmichael et al., 2006). Cross-sections show 5 km of vertical throw (3 km tilted strata exposed in the Warner Range, 2 km of basin fill imaged here) yielding a time-averaged slip-rate of 1-2 mm/yr. Large-magnitude Holocene rupture, modern seismicity, local geothermal activity and overpressured basin strata are all consistent with a high present-day slip rate.

Our September 2004 EARTHSCOPE-supported active and passive seismic experiment across the northwestern margin of the Basin-and-Range province (Lerch et al., 2007) included a relatively high-resolution vibrator-source profile (20-m CMP spacing) that extended from the surface trace of the SVF for 16 km to the east across Surprise Valley (*Figure 1*) as well as an 1100-kg shot-point on the east side of Surprise Valley recorded at 300-m spacing across the SVF (*Figure 2*).

Our explosive-source recording shows a reverse-moveout reflection modeled as from the SVF fault plane dipping 35 to 40° to >7 km depth (*Figure 2*).

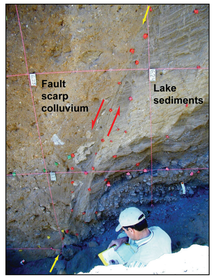
The SVF is the most significant reflector on our vibroseis profile (*Figure 3*) dipping 35°±3° basinward and visibly truncating intra-basin stratigraphy. Because our 2-D profile has a 35° intersection with the strike of the SVF, geometric correction for this obliquity steepens the observed migrated dip of 20°±2° to a true dip for the SVF of only 35°±3°.

We image a separate fault-splay above the main SVF with a true dip of 30°±5°.

Uplifted Cenozoic volcanic strata in the Warner Range dip 20° to the west, due to footwall block rotation during evolution of the SVF.
Restoring this rotation, the orientation of the SVF at its formation was 55°±3°, compatible with laboratory experiments.

Trenching for paleoseismic studies constrains the near-surface dip of the active SVF to be ~65° (S. Personius, pers. comm.), too steep to be the fault-plane that produced the ~20°-dipping Cenozoic stratigraphy in the Warner Range. This active fault trace is likely an extremely young feature in the Surprise Valley-Warner Range evolution, though it is not yet known whether it soles into, or cuts and offsets the less-favorable, now-shallow geometry (30°-35°) of the main SVF.

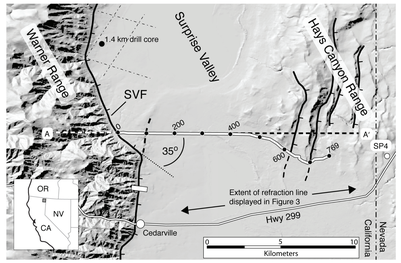
Surprise Valley may provide the chance to study the process of abandonment of a major active low-angle fault in favor of a new high-angle fault; the developing EARTHSCOPE FlexArray facility, now with triple the recording capability available to our 2004 experiment, offers the means to do so.



Active strand of the SVF exposed in the USGS trench (Figure 1) midway between our seismic images Figures 2 and 3. This fault is too steep to be the large-offset normal fault imaged on our reflection section, and too steep to have produced the rotated tilt-block of the Warner Range.

http://earthquake.usgs.gov/regional/imw/images/figure3.php

Figure 1 Shaded relief map of Surprise Valley, northeastern California

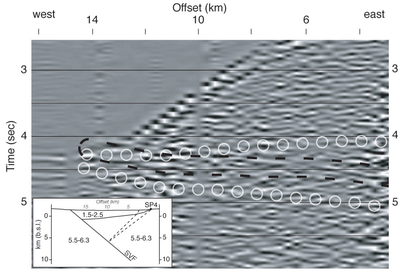


Vibroseis reflection profile is white line approximately 5 km north of the 2004 Stanford refraction line along Highway 299. Common midpoint (CMP) locations are spaced at 20 m. SVF: Surprise Valley Fault.

SP4: Shotpoint 4 from the 2004 Stanford refraction line (data in Figure 2).
Line A -A': location of geologic cross -section (Figure 3, top).

White rectangle across the SVF ~2km north of Cedarville is the USGS trenching project (S. Personious, pers. comm.).
Dash-dot lines are commercial vibroseis velocity profiles that indicate a basin-basement contact dipping 30° east (D. Benoit, pers. comm.).

Figure 2 Explosion-source shot-gather with reverse-moveout SVF reflection

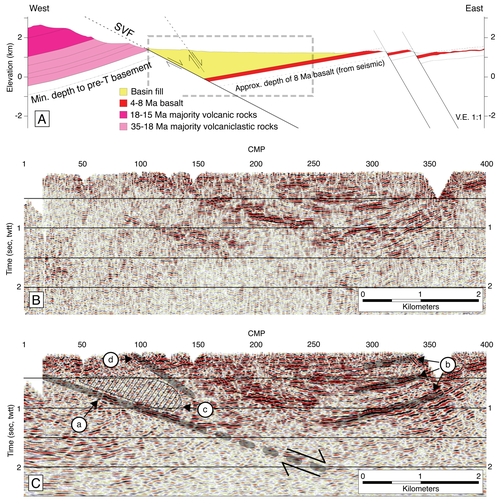


Shot-gather from Shotpoint 4 (2500 lbs explosive) recorded along Hwy 299 (Figure 1), and displayed with no move-out (no velocity corrections), shows first arrivals across Surprise Valley, and a reflection at ~4.5 s with "reverse move–out". Reverse move-out is defined by the reflection on far-offset traces (left-hand side) arriving earlier than the same reflection on near-offset traces (right-hand side), and geometrically requires a reflector that dips steeply back to the east, i.e. the SVF.

White circles superimposed on the data are modeled arrivals corresponding to an SVF that dips 30° or 45°, and arrive earlier and later than the observed phase. The observed phase, enclosed by a dashed black line, therefore corresponds to a dip of 35°-40° (precise dip depends on near-surface velocities, 2±0.2 km/s).

Schematic velocity model used in modeling is shown in inset, velocities are given in km/s, depths given in kilometers below sea level (no vertical exaggeration).

Figure 3 Geologic and seismic cross-sections of Surprise Valley



A: geologic cross-section, corresponding to line A-A' on Figure 1, showing pertinent Cenozoic units and major structures. Dashed grey outline: region contained in B and C.

B: unmigrated CMP stack of the Surprise Valley basin.

C: migrated image of the Surprise Valley basin.
(a) SVF appears as a continuous, moderate-amplitude east-dipping reflection that bounds the western side of the basin.
(b) prominent west-dipping reflectors on the eastern edge of Surprise Valley correspond to 10°-15° dipping 8-3 Ma volcanic strata.
(c) reflection-free region above the SVF is alluvium deposited along the range-front.
(d) fault splay of the SVF truncating west-dipping reflectors near CMP 100.

A, B & C: No vertical exaggeration based on basin-fill Vp=2 km/s.

References

Carmichael, I.S.E., Lange, R.A., Hall, C.M., & Renne, P.R. 2006. Faulted and tilted Pliocene olivine-tholeiite lavas near Alturas, NE California, and their bearing on the uplift of the Warner Range. Geol. Soc. Am. Bull. 118, 1196-1211.

Lerch, D.W. 2007. Geophysical and geological characterization of Cenozoic tectonism and magmatism across the northwestern margin of the Basin and Range Province. Ph.D. thesis, Stanford University, 142 pp.

Lerch, D.W., Klemperer, S.L., Glen, J.M.G., Ponce, D.A., Miller, E.L., & Colgan, J.P. 2007. Crustal structure of the northwestern Basin and Range and its transition to unextended volcanic plateaus, Geochemistry, Geophysics, and Geosystems, 8(Q02011), doi:10.1029/2006GC001,429.

Lerch, D.W., Klemperer, S.L., Egger, A.E., Colgan, J.P., & Miller, E.L. Reflection profiling of a shallow-angle (35°) late-Miocene to Recent Basin-and-Range normal-fault: Surprise Valley, CA. Geology, in prep.

Lerch, D.W., Klemperer, S.L., Stokoe, K., & Menq, F.-Y. Application of the NEES T -Rex vibrator in reflection profiling of extended continental crust. Seismological Research Letters, in prep.

Appendix

Utility of the NEES T-Rex vibrator and Earthscope Texan pool for active-source seismic profiling

In September 2004, Stanford University and UT-Austin collected crustal reflection and refraction data with the Network for Earthquake Engineering Simulation (NEES) tri-axial (T-Rex) vibrator in two separate surveys: (1) a 40-km crustal -scale profile in the Black Rock Desert and Black Rock Range, NV; and (2) a 16-km 'high -resolution' basin imaging profile in Surprise Valley, CA (*Figure A1*). Both experiments were completed within the framework of our larger, 300-km wide-angle refraction line recorded by IRIS-PASSCAL Texans as a prototype for the FlexArray in the first EARTHSCOPE active-source experiment.

T-Rex (below), acquired by NEES-UT Austin in 2002, is a 29,000 kg buggy-mounted vibrator with a tri-axial mass, capable of generating P, SV, and SH waves. Given its relatively large mass, and hence its high peak force output of 267 kN, T-Rex is a potentially viable source for single-vibrator crustal profiling.

The integration of T-Rex into our crustal-scale (Lerch et al., 2007) and 'high-res' profiles (this poster) revealed its strengths and limitations, as well as the logistical and quality-control problems associated with recording continuous vibrator data with stand-alone Texan seismographs.

Single 60-sec sweeps with T-Rex consistently produced coherent reflected energy to 1-2 sec two-way time (*Figure A2*), and into the lower crust on our best data with high fold stacking (*Figure A3*). Refracted energy from single sweeps consistently reached offsets ≥10 km, and with stacking of 10 to 30 sweeps, up to 50 km (*Figure A3*). These propagation distances afforded a useful reflection image of the Surprise Valley basin (*Figure 3*), and an upper-crustal velocity model of the Black Rock Desert and Black Rock Range (Lerch et al., 2007), illustrating the value of this new addition to the crustal-seismology community.

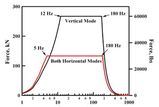
The 16-km "high-res" profile required 4 days, with about 200 one-minute sweeps (the longest then possible with T-Rex) recorded in each 4-hour recording window. Two 4-hour profiling windows were recorded each day, and T-Rex was re-fuelled by hand on-site each mid-day and evening. The profile was shot through a fixed spread, with 400 Texans maintained on the line. Because of limited Texan memory (32 Mb in most instruments), three times a day (before, between and after the profiling sessions) 60 Texans were retrieved for downloading, and replaced by 60 fresh Texans in their places. In this manner the entire profile could have been maintained indefinitely by a small crew.

Notwithstanding the success of our shallow reflection profile, our attempts to record lower-crustal reflectivity were only marginally useful.
Our attempts to record useful shear-wave energy, whether using vertical phones on Texans or using 3-component 4.5 Hz phones with 3-channel Refteks, were more disppointing, so that our hopes of studying mid-to-lower-crustal anisotropy, and of producing a basin Vs model, were not realised.

Figure A1: Location of our experiments in the northwestern Basin and Range. Black circles: 2004 Stanford seismic refraction geophone locations (appears as a solid line west of the Santa Rosa Range due to dense instrument spacing).
Thin line labeled RP in Surprise Valley corresponds to the reflection profile described in this poster. Arrows surrounding BRRP correspond to the extent of our crustal-scale reflection profile across the Black Rock Desert and Black Rock Range.
Inset photos: (A) T-Rex; (B) indentation in road surface from pad cones (pen for scale); (C) plywood pad added to baseplate to protect paved road surfaces.

Figure A2: Source gather from Surprise Valley 'hi-res' profile. Four one-minute 5-80 Hz sweeps (at 10-m spacing) stacked to create a single, 40-m source array. First-breaks have been muted, and a 10-14-36-42 Hz bandpass filter applied.

Figure A3: Source gather from crustal profile (stack of ten coincident one-minute sweeps, bandpass-filtered 4-6-36-42 Hz, with predictive deconvolution. Coherent arrivals are clearly visible to offsets of 20 km, with discontinuous energy visible to 50 km. Weak reflections visible between 8 and 9 s at offsets > 20 km.



T-Rex and its theoretical force output http://nees.utexas.edu/Equipment-T-Rex.shtml

Figure A1

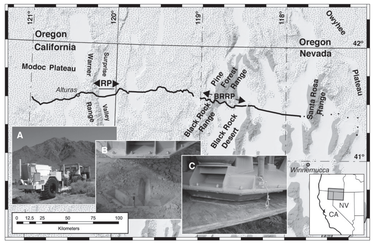


Figure A2

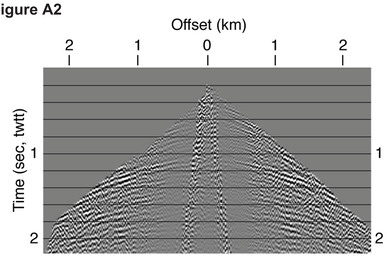


Figure A3